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Relation of Urban Model Performance to Stability

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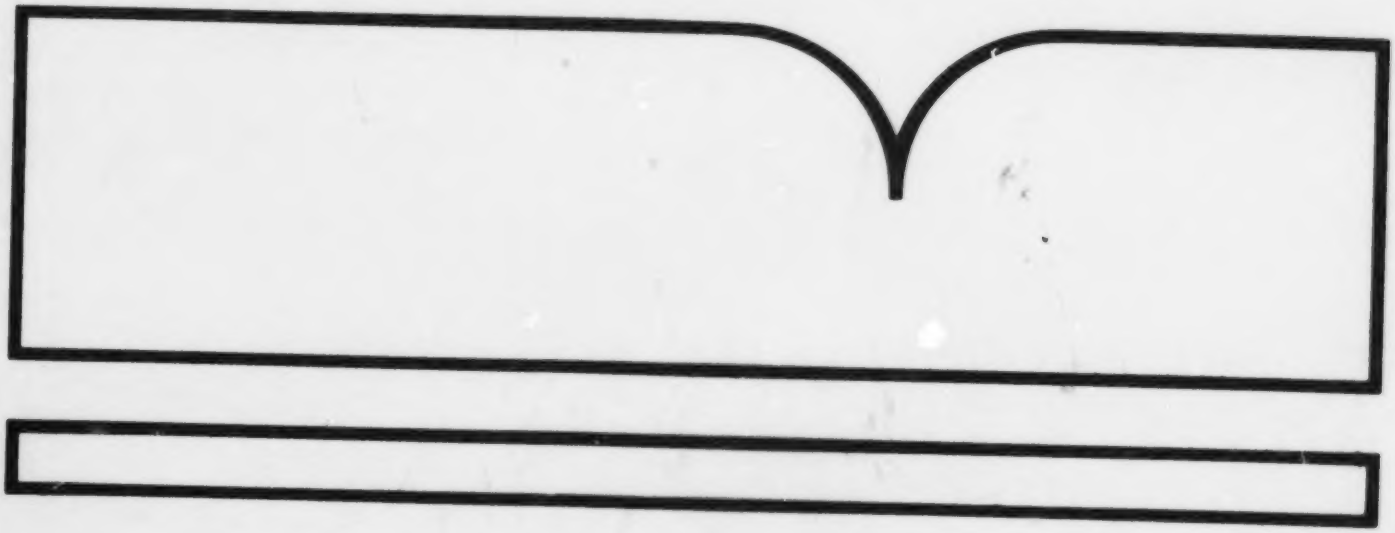

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THE RELATION OF URBAN MODEL PERFORMANCE TO STABILITY

by

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16. ABSTRACT

The RAM model performance in estimating SO_2 concentrations in St. Louis, MO for 1976 has been discussed in several previous papers by the authors. In these studies the model estimates were compared to the observed concentrations of SO_2 at 13 sites in the St. Louis metropolitan area. An analysis is made evaluating the RAM model performance in estimating the infrequently occurring high concentration values. Previous comparisons have been criticized for not assuring that the modeled high concentration values occurred during similar meteorological conditions as when the high concentrations were observed. To address these concerns, the data are sorted by stability class and wind speed before the comparison statistics are computed. This allows a meaningful comparison of average concentrations and high values for each data grouping. Results are displayed graphically and provide insight into the variation of model performance with both stability class and wind speed. The resulting comparisons suggest that the RAM model concentration estimates may have a bias towards underestimating concentrations during very unstable conditions and overestimating concentration values during very stable conditions.

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THE RELATION OF URBAN MODEL PERFORMANCE TO STABILITY

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INTRODUCTION

Previous studies (Turner and Irwin, 1983, and Ruff, 1981) have made use of data collected in the Regional Air Pollution Study (RAPS) in St. Louis to evaluate the urban model RAM (Turner and Novak, 1978). RAM estimates short-term (hourly) dispersion using the Gaussian steady-state modeling concepts (Novak and Turner, 1976). Concentrations from point sources are calculated by evaluation of a single equation for each source receptor pair. Concentrations from area sources are computed using the narrow plume simplification (Gifford and Hanna, 1971), with the two-dimensional integral that expresses the total area-source contribution to concentration being approximated by a one-dimensional integral that only involves knowledge of the distribution of the area-source emissions along the line in the direction of the upwind azimuth from the receptor location. Emphasis was upon averages and extremes found from the data set for the year 1976.

These studies indicated that although the model overestimated concentrations for some measurement stations and underestimated concentrations for other stations, for the network as a whole, there appeared to be little bias for both annual means and second-highest concentrations. This was not to say that the model simulated the pollutant transport and dispersion well for there could be compensating errors to arrive at a reasonable annual value. And although the proper magnitude was obtained for the second-highest values, it had not been determined that the second

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highest occurred in the atmosphere under similar conditions that caused the modeled second-highest concentrations. In fact, examination of the measured and model estimated concentrations suggested that the highest values produced by the model occurred with different stability classes than the stability classes corresponding to the highest measured concentrations. Here we will stratify the modeled and measured concentrations by stability to see if there is any systematic bias.

ANALYSIS PERFORMED

Several measures related to data quality were available for the SO_2 measurements. Both the percent of zero drift and the span drift between successive calibrations (approximately every 24 hours) were available. Also the number of minutes of acceptable values for each hour was available. For this study a timeliness criteria of greater than or equal to 45 minutes was used. Quality criteria of span drift of no more than 10 percent and zero drift of no more than 1 percent of full scale were used. Full scale was 1 ppm (about 2600 $\mu g/m^3$). Use of these criteria resulted in a minimum of 58.1 percent usable data for station 106 to a maximum of 68.9 percent usable data for station 103.

A single wind speed and a stability class representative of the urban area is available for each hour. The Pasquill stability classes were determined using hourly cloud cover and ceiling height at the St. Louis Airport (Lambert Field) and an hourly urban average wind speed determined from the wind measurements made at the air quality sampling locations. There are eight classes: A, B, C, D (day), D (night), E, and F based on the Pasquill classification and G which is more stable than Pasquill's F. Using the wind speeds from the data in each stability class, a median speed was selected for each class so that the data within that class could be partitioned into two nearly equal groups. The dividing wind speeds, and the number of periods in the resulting 16 stability - wind speed categories are given in Table 1.

For each stability - wind speed category the average concentration and the maximum concentration for both the model estimates and the measurements were selected for further analysis. (Data meeting the previously discussed criteria were used for the measurements; all data were used for the model estimates.) Table 2 gives the average concentrations and Table 3 gives the maximum concentrations for the measurements and the model estimates for the 16 categories for each measurement station. The geographic position of these stations is given by Myers and Reagan (1975), and Turner and Irwin (1983).

Table 1. Number of One-Hour Periods in Analysis Categories

Stability Class	A	B	C	DD	DN	E	F	G
Dividing Wind Speed	2.0	2.7	3.6	5.0	4.4	3.3	2.4	1.4
Number in High Wind Speed Class[a]	47	312	574	902	905	748	652	187
Number in Low Wind Speed Class	47	330	555	944	920	711	734	224

[a] cases with wind speeds greater than or equal to dividing wind speed.

Table 2. Average 1-Hour SO_2 Concentration Model Estimates and Measurements ($\mu g/m^3$) for Each Stability - Wind Speed Category. (The Number of Values in Each Category is Given in Table 1 for the Estimates and on the Third Line for Each Station for the Measurements.)

STABILITY CLASS		A		B		C		DD		DN		E		F		G[a]	
WIND SPEED CLASS		L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
STATION																	
101	est	34	22	38	26	56	35	57	35	76	48	130	112	134	125	202	121
	meas	79	32	70	37	63	45	51	33	58	42	57	79	73	67	47	53
	no.	16	12	193	174	342	319	610	655	559	600	425	442	421	330	120	101
103	est	26	17	25	20	30	21	28	19	35	19	69	51	67	55	98	64
	meas	72	20	56	36	67	36	34	29	38	28	31	39	30	31	23	20
	no.	29	19	221	208	405	408	698	697	645	613	494	489	466	392	146	120
104	est	45	30	35	28	50	31	46	33	57	34	101	83	100	89	157	101
	meas	92	27	111	49	177	102	94	71	132	77	161	148	127	142	144	91
	no.	25	10	194	173	358	351	659	698	590	622	454	470	424	344	133	97
105	est	49	62	50	44	50	30	38	15	38	17	78	43	73	53	114	74
	meas	68	50	65	46	63	48	47	27	50	29	49	30	48	35	40	55
	no.	30	17	211	190	387	378	706	672	611	643	481	506	457	389	135	102
106	est	23	15	28	19	28	18	32	16	36	19	65	44	70	47	117	58
	meas	72	37	88	42	66	53	56	39	52	43	58	52	85	48	41	57
	no.	23	16	200	183	330	343	600	590	524	488	431	403	403	345	127	95
108	est	16	11	19	20	25	17	22	16	29	18	52	44	51	42	77	50
	meas	52	24	51	43	51	43	36	30	38	40	34	46	23	34	15	20
	no.	22	14	194	185	360	373	707	731	617	646	462	483	443	379	133	114
113	est	16	12	19	18	18	14	20	11	23	13	43	32	39	32	67	36
	meas	41	26	51	51	50	35	35	22	37	29	39	37	34	37	25	40
	no.	26	14	198	178	344	332	649	630	580	600	471	452	431	323	110	98
114	est	22	16	21	20	18	14	23	14	26	16	44	29	39	28	61	43
	meas	65	17	45	33	42	40	38	29	43	34	33	35	29	28	19	27
	no.	29	13	198	202	364	360	689	681	613	671	478	498	456	384	129	124
115	est	26	16	18	17	23	17	18	20	25	24	44	52	41	33	47	51
	meas	77	30	45	38	40	27	24	21	32	31	21	41	15	21	11	12
	no.	28	20	194	210	382	388	700	651	627	635	471	440	460	389	127	107
116	est	13	11	11	12	14	11	12	12	15	14	24	31	23	20	34	24
	meas	40	16	42	24	31	22	22	21	36	21	21	23	20	19	17	18
	no.	29	23	220	209	370	363	633	309	562	552	468	435	453	364	142	110
120	est	10	11	11	15	12	11	13	9	12	9	26	12	22	14	31	27
	meas	33	35	36	47	30	27	31	23	30	22	25	22	23	19	19	19
	no.	24	24	202	208	366	375	689	662	590	627	457	475	472	369	125	113
121	est	11	21	17	20	16	16	18	8	18	9	28	14	27	15	36	29
	meas	47	36	58	39	40	31	33	22	32	23	32	27	31	25	22	25
	no.	18	14	187	165	319	327	618	685	584	638	440	434	380	349	131	92
122	est	13	11	11	12	12	9	10	11	12	14	18	19	18	18	24	17
	meas	42	32	41	26	3*	34	27	25	27	27	24	32	16	24	19	13
	no.	21	15	187	165	307	305	605	620	529	596	400	431	408	329	121	90

[a] Stability classes A-F as defined by Pasquill. G are those cases more stable than Pasquill's F.

Table 3 Maximum 1-Hour SO_2 Concentration Model Estimates and Measurements ($\mu g/m^3$) for Each Stability - Wind Speed Category (The Number of Values in Each Category is Given in Table 1 for the Estimates and on the Third Line for Each Station for the Measurements.)

STABILITY CLASS		A		B		C		DD		DN		E		F		G[a]	
WIND SPEED CLASS		L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
STATION																	
101	est	137	82	213	148	326	181	428	258	448	271	853	546	857	664	1101	547
	meas	224	214	1211	281	1175	531	1068	654	1138	503	1338	1310	1543	1250	251	258
	no	16	12	193	174	342	319	618	655	559	680	425	442	421	330	120	101
103	est	129	100	148	111	288	180	251	238	378	283	519	314	487	320	622	459
	meas	227	87	842	263	1845	343	343	522	498	240	289	565	419	559	182	179
	no	29	19	221	208	485	408	698	697	845	613	494	489	466	392	146	120
104	est	217	140	214	132	444	222	635	404	643	294	1250	543	1292	680	864	729
	meas	242	82	1366	281	1767	1712	1998	1756	2099	1066	2135	1807	1966	1724	1455	1221
	no	25	10	194	173	358	351	659	698	590	622	454	470	424	344	133	97
105	est	252	432	407	392	407	467	423	305	385	291	737	431	842	355	747	391
	meas	266	137	271	341	500	944	537	325	556	325	417	244	582	279	282	411
	no	30	17	211	190	387	378	706	672	811	643	481	508	457	389	135	102
106	est	99	85	183	163	227	217	338	268	332	328	598	383	718	306	548	294
	meas	240	102	366	429	789	734	1260	459	1268	458	319	549	772	829	249	365
	no	23	16	200	183	330	343	600	590	524	488	431	403	403	345	127	95
108	est	91	54	129	130	229	210	300	245	306	268	575	398	493	355	856	396
	meas	138	98	295	290	387	329	354	324	484	339	2483	421	252	288	181	171
	no	22	14	194	185	360	373	787	731	817	846	462	483	443	379	133	114
113	est	86	69	181	133	247	188	231	155	317	279	562	311	388	413	565	372
	meas	136	70	362	1516	410	307	371	267	414	405	358	496	396	737	199	290
	no	26	14	198	178	344	332	649	630	560	680	421	452	431	323	110	98
114	est	114	61	158	157	197	205	357	203	456	228	869	395	746	479	1217	780
	meas	164	43	227	276	603	1062	1021	517	555	295	559	332	308	345	220	193
	no	29	13	198	202	364	360	689	681	613	671	478	498	458	394	129	124
115	est	214	136	393	132	436	188	452	257	853	622	1428	937	1675	553	1875	1054
	meas	253	140	323	328	270	286	247	238	389	418	247	536	211	223	170	92
	no	28	20	194	210	382	368	700	651	627	635	471	440	480	389	127	107
116	est	137	75	186	113	287	179	247	201	367	233	377	385	548	239	546	422
	meas	178	57	391	297	242	473	503	614	598	306	240	246	1079	323	144	231
	no	29	23	220	209	370	383	633	609	562	552	468	435	453	364	142	110
120	est	78	69	111	203	246	218	352	247	313	278	445	419	427	297	288	333
	meas	99	126	279	856	394	294	248	1048	300	339	484	309	459	193	169	128
	no	24	24	202	208	366	375	669	662	590	627	457	475	472	369	125	113
121	est	85	167	347	297	442	387	467	214	448	351	624	323	512	218	518	358
	meas	110	83	358	285	325	251	250	367	415	276	301	485	322	388	208	147
	no	18	14	167	145	319	327	618	665	584	638	440	434	389	349	131	92
122	est	150	95	153	214	295	153	183	195	258	209	374	313	406	270	289	233
	meas	285	89	374	380	491	353	576	519	416	309	558	285	232	291	339	108
	no	21	15	187	165	307	305	605	620	529	596	400	431	408	329	121	90

[a] Stability classes A-F as defined by Pasquill. G are those cases more stable than Pasquill's F.

These data were graphed in various ways to examine performance by stability and by wind speed. Figures 1 through 5 are examples. Concentrations are shown on a logarithmic scale. The upper set are maxima (1-hour) for each stability - wind speed category. The lower set are averages for each stability - wind speed category. Measured concentrations (stippled) are on the left with model estimates on the right within each stability class. Concentrations for the light wind speed group are indicated by the heavy horizontal line. Graphs of this type were made for all 13 measurement locations and examined.

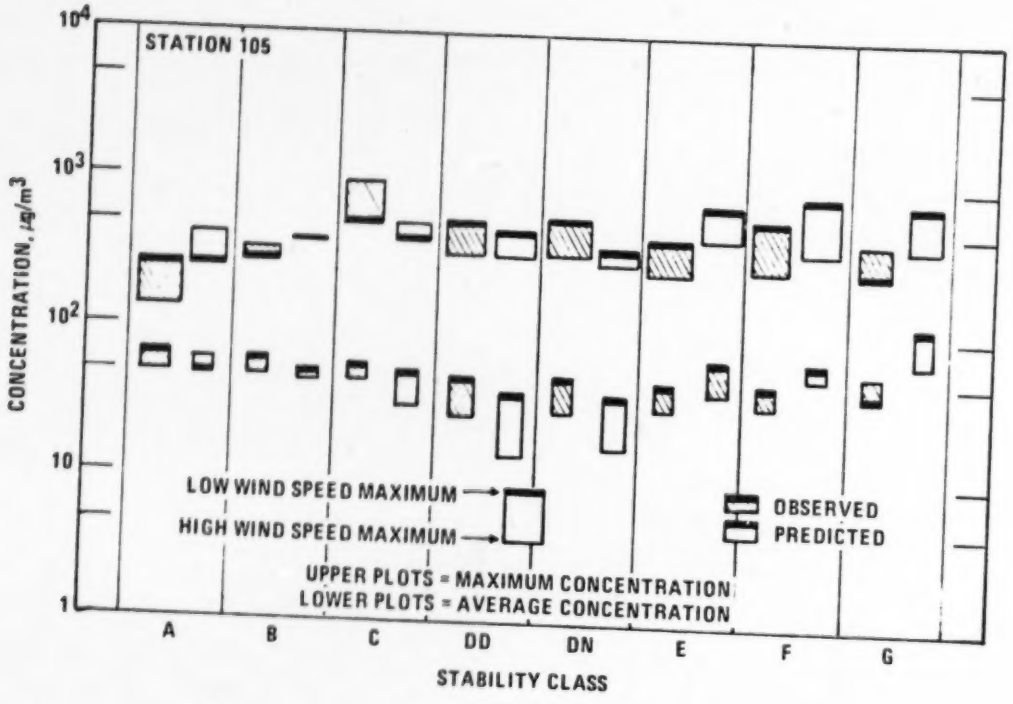

Fig. 1. Maximum and average SO_2 concentrations for each stability - wind speed category for station 105.

DISCUSSION

Comparison of Averages

For both low and high wind speed categories, the model yields lower average concentrations for the most unstable category A, with a slight trend to higher values for the stable categories E-G. Station 108 (Figure 3) for both wind speeds and station 121 (Figure 5) for low wind speeds are typical. Station 105 (Figure 1) with low average concentration values for D (day and night) is the exception. The trend toward higher values during stable categories is more apparent in the results for the low wind speed groups than the results for the high wind speed groups.

The measurements generally exhibit higher average concentrations during A stability with lower average concentrations during stable conditions. This trend is in contrast to that seen for the model results. As with the model results, the trends are more easily seen for the low wind speed groups than for the high wind speed groups.

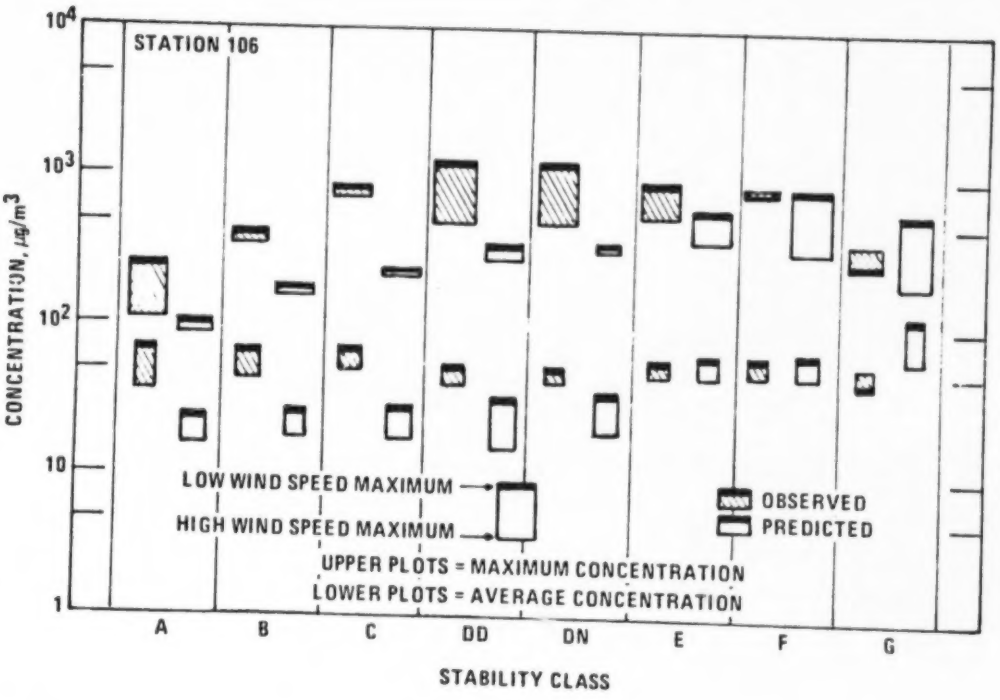

Fig. 2. Maximum and average SO_2 concentrations for each stability - wind speed category for station 106.

Comparison of Maxima

The trends seen in the model estimates for peak 1-hour concentrations are quite similar to the trends seen in the average estimated concentrations. Typically, the model yields lower peak concentrations during A stability than during stable conditions, such as at station 106 (Figure 2). Exceptions are station 121 (Figure 5) with nearly the same concentrations for classes B through G, and stations 115 (Figure 4) and 120 with lower concentrations with G stability than with F for low wind speeds.

The peak measured concentrations are generally lower for the extremes in stability (very unstable or very stable) with the highest values occurring during B through F stability. Stations 105 (Figure 1) and 121 (Figure 5) display little change in the concentration values for B through G with peaks most frequently with D night stability with low wind speeds and D day or E for high wind speeds. Several stations, 105 (Figure 1) and 113, have large peaks with B and C stability.

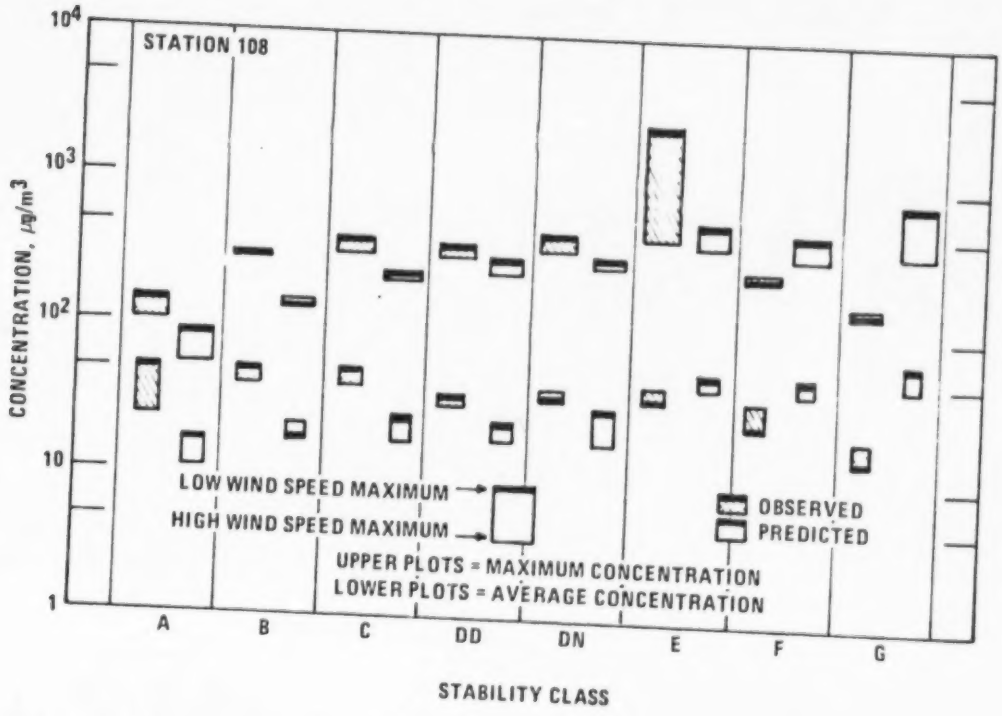

Fig. 3. Maximum and average SO_2 concentrations for each stability - wind speed category for station 108.

Comparison of Averaged Rank Order

Further calculations were made in an attempt to summarize the trends noted above over all 13 stations. For the high and low wind speed categories separately, for each station, each stability category was assigned a rank 1 to 8, according to the ranking of the concentrations. For example, for station 105 (Fig. 1), for peak measurements at high wind speeds stability category C has a rank of 1, category A a rank of 8. These ranks were then averaged for each stability category over the 13 stations. These results are displayed in Figure 6. Solid lines connect the mean ranks for low wind speeds; dashed lines connect the mean ranks for high wind speeds. When averaged over the 13 stations some definite trends appear. Modeled concentrations for both wind speed groups and for both peak and average concentrations produce low average rank values (6 to 7) for unstable conditions and high average rank values (1 to 2) for stable conditions.

For average measured concentrations for low wind speeds, the plots of average rank suggest quite the opposite trend occurs:

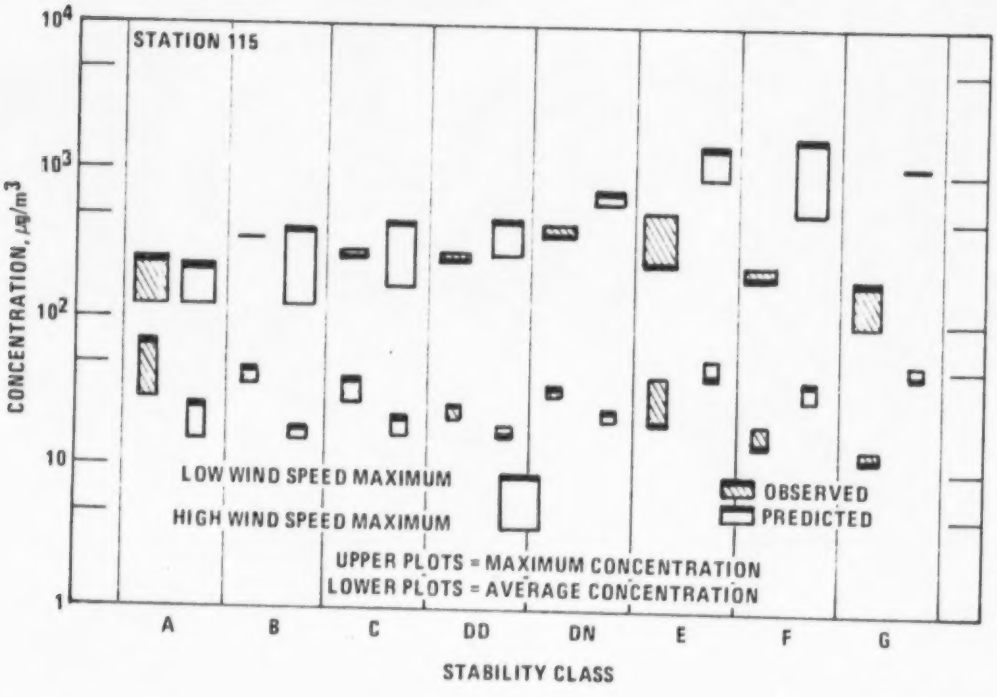

Fig. 4. Maximum and average SO_2 concentrations for each stability - wind speed category for station 115.

high concentrations for unstable situations and low concentrations for stable conditions. For the high wind speed categories there is no overall trend for the measured averages. The plots of average rank for the 1-hour peak concentrations measured are very similar for both wind speed categories, suggesting low concentrations for A and G stabilities with a relatively flat distribution of average ranks for stabilities B through F.

SPECULATION ON STABILITY-RELATED PERFORMANCE

There are several possible causes that might explain the lack of agreement in the modeled and measured concentration trends with stability.

Building Downwash

The tendency to underestimate concentrations under higher wind speeds may be related, in part, to the model's rather simplistic view of dispersion. Building wake effects on dispersion and plume rise are not considered in the modeling. Observed maximum concentrations are greater for the high wind speed cases

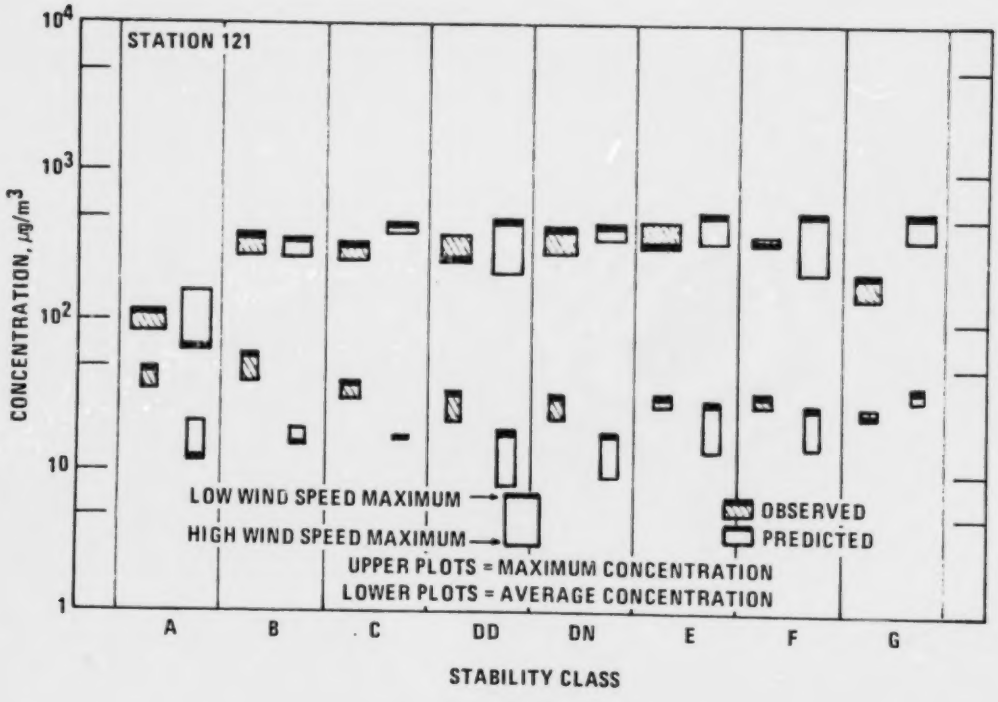

Fig. 5. Maximum and average SO_2 concentrations for each stability - wind speed category for station 121.

than for the low wind speed cases at stations 105, 113, 114, 115, 120, and 121. (The highest modeled concentration at each receptor occurs with low wind speed categories.)

Plume Penetration of Stable Layers

Underestimates during daytime may be related to the manner in which buoyant emissions are modeled. It is quite likely that the model computes full penetration of the rising plume of effluent into the elevated stable layer above the surface based mixed layer more often than really occurs. This has the effect of lowering daytime estimated concentrations. Brower (1980) and Weil and Brower (1982) have pointed out instances where a rural model employing a plume rise formulation similar to that in RAM estimates the plume above the mixing height, yet there are measurable ground-level concentrations, thus the model underestimates concentrations. This could as easily occur with urban modeling.

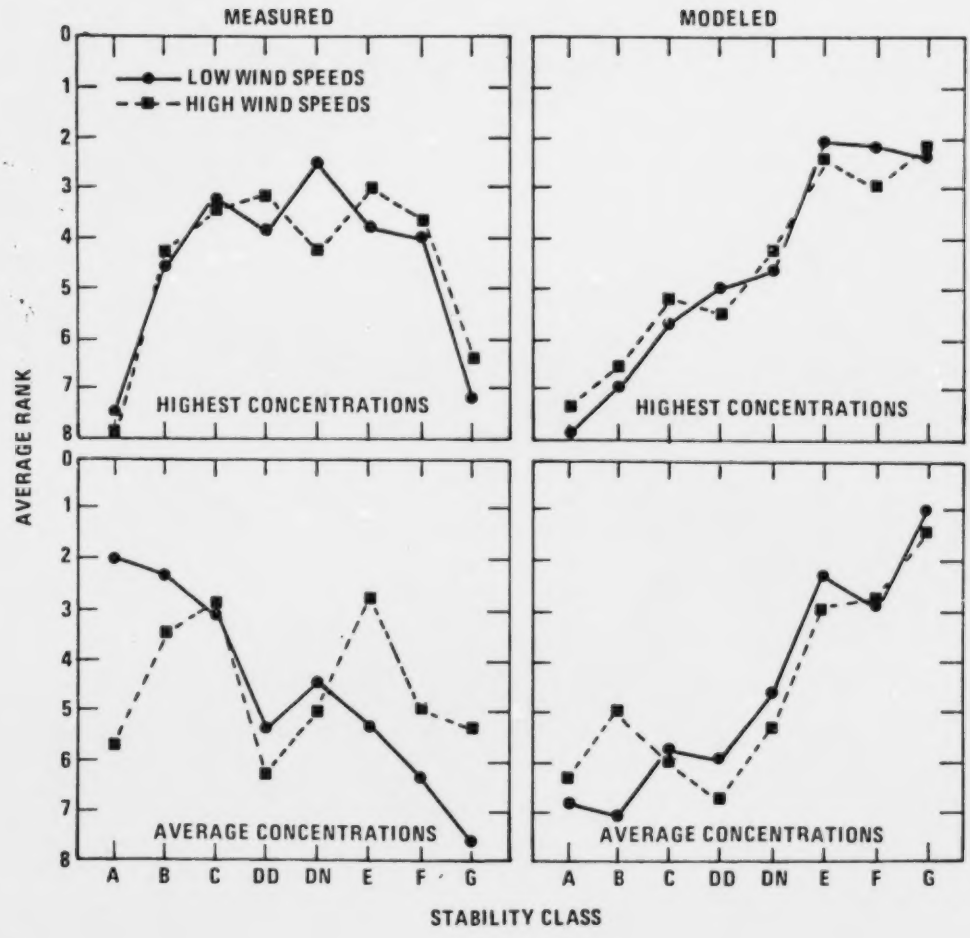

Fig. 6. Mean rankings of maximum and average concentrations over the 13 stations for each stability - wind speed category (solid lines for low wind speeds, dashed lines for high wind speeds).

Partitioning of Emissions

Of greatest importance in the authors' opinion is the strong sensitivity of the modeling results to the manner in which the emissions are characterized. The pattern of model estimates being highest under stable conditions and lower under unstable conditions is the result one might expect from modeling low level sources. The emission inventory of the St. Louis area for SO_2 for RAPS has only 208 sources considered as point sources. All other sources were included in the inventory in the area source cate-

gory with relatively low emission release heights. If more of the emissions had been treated as point sources, the effect would be to decrease concentrations under stable conditions and to increase concentrations (locally near the point source) under neutral and unstable conditions since each emission would be from a point rather than a larger area. This is speculated by the authors to be a major cause of the behavior of model estimates with stability. Inclusion of point sources in the inventory as area sources was identified by Ruff (1983) as a possible cause of stability bias in the model performance.

Finally, if the modeled emission rates for either the point sources or the area sources are too large during the nighttime hours as compared to the real emissions, this would likely result in an overestimation of concentration values during stable conditions. We cannot eliminate this from the realm of possibility as the diurnal cycle of emissions for most all of the emissions was modeled in developing the emissions inventory. Only for the largest point sources were hourly records kept of the fuel usages, for use in developing emission rates.

CONCLUSIONS

Previous examinations of the performance of the urban model RAM against the RAPS data base have shown considerable station-by-station scatter but little evidence of overall bias regarding average concentrations and second-highest concentrations for 1-, 3-, and 24-hour time periods. This report has partitioned the data by stability and two wind speed groupings within each stability category. Examination of maximum 1-hour concentrations and average concentration for each category reveal quite different model behavior from that of the measurements. For model estimates for both maxima and averages, the largest concentrations occur with stable conditions and low wind speeds. In contrast to this, for measurement maxima the largest concentrations occur over a range of stabilities from slightly unstable to moderately stable with low wind speeds at some stations and high wind speeds at other stations. For measurement averages, the highest concentrations occur for the most part with A stability for the low wind speeds and have no definite trend for the high wind speeds. The authors have speculated as to possible causes for the behavior observed. Although the exact causes were not determined for the bias seen in the comparison results, the fact that the bias was seen to be an apparent function of stability is considered a significant advance. These results should help direct research activities towards discovery of the causes.

Similar analyses to those shown here will allow assessment to be easily made of any resulting improvements.

ACKNOWLEDGEMENTS

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